

## Trend analysis of temperature and precipitation in Trarza region of Mauritania

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### ABSTRACT

Trend analysis of annual temperature and precipitation time series data collected from three stations (Boutilimit (station 1), Nouakchott (station 2) and Rosso (station 3)) has been used to detect the impacts of climate change on water resources in Trarza region, Mauritania. The Mann–Kendall, the Spearman's rho, and the Sen trend test were used for the trend identification. Pettitt's test was used to detect the change point of the series while the Theil–Sen approach was used to estimate the magnitude of the slope in the series. For precipitation, two stations (1 and 3) indicated statistically significant increase in trends. In the case of temperature, almost all the stations show statistically significant increasing trends in the maximum, minimum, and average temperatures. The magnitude of precipitation detected by the Theil–Sen test for stations 1 and 3, respectively, was found to be at the rate of 2.93 and 3.35 mm/year at 5% significance level. The magnitude trend of temperature detected by the Theil–Sen approach was found to be at the rate of 0.2–0.4 °C per decade for almost all the stations. The change points of temperature trends detected by Pettitt test are found to be in the same year (1995) for all the stations.

**Key words** | arid region, Mauritania, precipitation, temperature, Trarza, trend analysis

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### INTRODUCTION

Global climatic change has attracted the attention of many scientists in recent years. Studies of the effect of climate change are mostly monitored by using air temperature and precipitation trends rather than hydrologic variables. Many studies have provided evidence that temperature and precipitation increased in recent years. [New \*et al.\* \(2001\)](#) collected precipitation data from a number of countries to identify trends in precipitation and they concluded that daily precipitation had increased during the twentieth century. A study by [Jones \*et al.\* \(1999\)](#) on surface air temperature and its change over 150 years showed that the global temperature during the periods 1925–1944 and 1978–1997 rose by 0.37 °C and 0.32 °C, respectively. [Lettenmaier \*et al.\* \(1994\)](#) analyzed the hydro-climatological trends in the continental United States for 1948–1988 and they found increasing trends at 50% of the stations for

temperature in March, as well as precipitation which increased from September to December at 25% of the stations. [Chen \*et al.\* \(2009\)](#) investigated the historical trends of meteorological drought in Taiwan by means of long-term precipitation records, and they detected positive trend in the daily precipitation time series for dry days all over Taiwan.

Mauritania receives very little rainfall at any time of year. The southernmost part of the country reaches the semi-arid region called the Sahel. Mauritania has a wet season between July and September, with up to 200 mm of rainfall per month. The mean temperatures are highest in the southern part of the country and lowest in the north for most of the year. Since the mid-1960s, long-term drought has killed most of the livestock and forced nomad populations to resettle, creating new villages or enlarging small

cities in Mauritania (Arnaud 1999). Many other inhabitants moved towards the capital Nouakchott where the population increased from 6000 in 1962 to 760,000 in 2001 (Salama *et al.* 1991; Niang *et al.* 2008). However, there are few studies of trends of meteorological variables, such as precipitation and temperature, in Mauritania. MacSweeney *et al.* (2008) used a consistent approach for 52 developed countries to produce an analysis of climate data. Their results showed that the mean annual temperature in Mauritania has increased by 0.90 °C since 1960, with an average rate of 0.19 °C per decade. The mean annual rainfall over Mauritania has not changed with any consistent trend since 1960. Some unusually high rainfalls have occurred in very recent years (2000–2006), which were not part of a consistent trend analysis in the study of MacSweeney *et al.* (2008).

The historical hydro-climatic precipitation and temperature recorded data are generally used for planning and designing water resources projects. The changes in these meteorological variables in recent years have triggered research to find effective trend identification tests to investigate and analyze regime changes in the time series data. Many of these trend tests are classified into parametric and non-parametric methods. Parametric trend tests are more powerful than non-parametric ones (Shadmani *et al.* 2012). However, the parametric trend tests require data to be normally distributed. In contrast, the non-parametric trend tests do not assume any specific distribution.

The non-parametric Mann–Kendall test (MK test) and Spearman's rho test (SR test) are commonly used for detecting trend of hydro-meteorological variables (Gellens 2000; Garbrecht *et al.* 2004; Kahya & Kalaycı 2004; Shadmani *et al.* 2012). The reason for using these two nonparametric rank-based statistical tests is that they have an ability to identify the monotonic trends (upward and downward trends) in the time series data. These tests can deal with non-normal data, missing values, seasonality, censoring (detection limits), and serial dependence (Hirsch & Slack 1984). However, the power of these methods has not been well documented. Yue *et al.* (2002) investigated the power of these two tests and concluded that their power (decrease or increase) depends on different variables including slope of the trend, sample size, pre-assigned significance level, and the variation of the time series.

Şen (2012) provided a new trend analysis method, which is able to identify the trend in the time series especially in terms of low, medium, and high values of the data. This method is valid whatever the sample size, serial correlation structure of the time, and non-normal probability distribution functions (Şen 2012).

Many studies use the Theil–Sen approach which was described by Hirsch *et al.* (1982) for estimating absolute values for slope (Yue *et al.* 2002; Gallego *et al.* 2006; Chen & Grasby 2009; Shadmani *et al.* 2012; Some'e *et al.* 2012). Pettitt's test (Pettitt 1979) is used to detect change points in time series (Tomozeiu *et al.* 2000; Mu *et al.* 2007; Zhang *et al.* 2008; Gebremicael *et al.* 2013).

In this study, 44 years of meteorological records (collected at three stations) were used to investigate trends in precipitation and temperature time series in Trarza region in Mauritania. The MK test, the SR test, and the Şen trend test were used for trend identification in the time series and the Pettitt test for detecting the change point at the time series. The Theil–Sen approach was used to estimate the magnitude of the slope in the precipitation and temperature time series.

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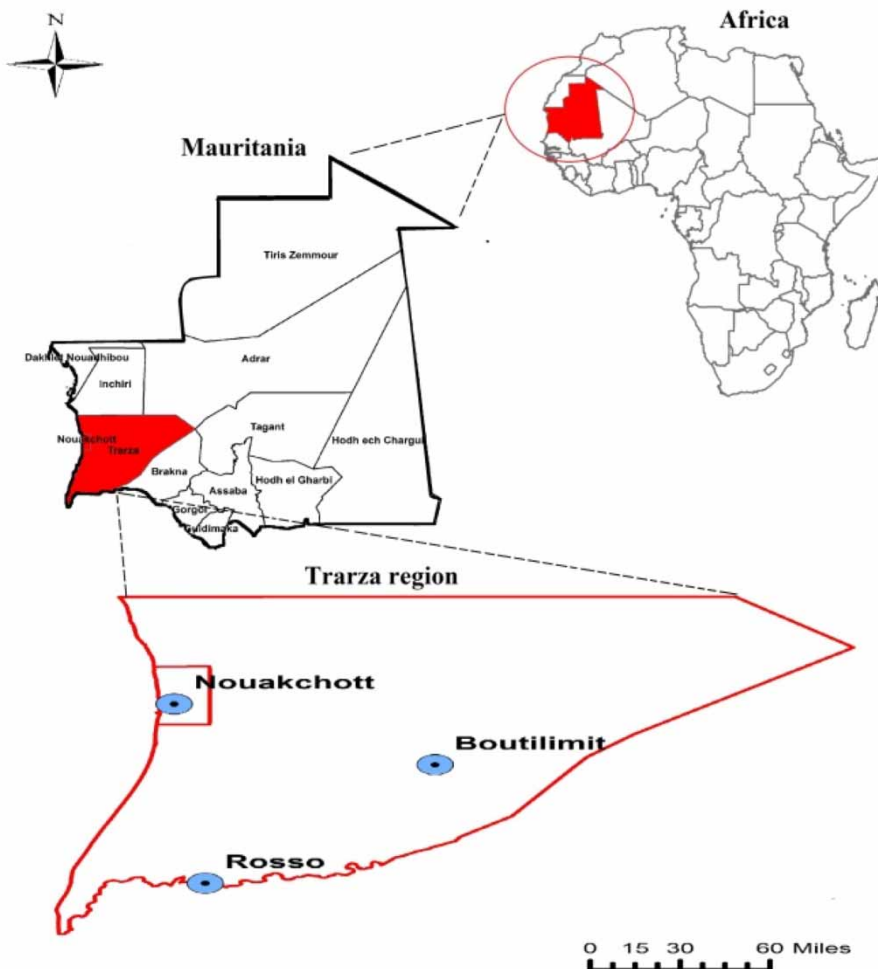
## STUDY AREA AND DATA

### Study area

Trarza is a region in the southwest of Mauritania (Figure 1) with total area of 67,800 km<sup>2</sup>. It is one of the most populated regions in Mauritania. The water resources in Trarza region support a range of uses from urban water supply to agriculture. The source of the groundwater is the Trarza aquifer covering about 40,000 km<sup>2</sup>. This aquifer plays a very important role as the main ground source of water for Mauritania. Senegal River (located in the west of the region) is Mauritania's only permanent waterway and is used for irrigation, transport, drinking, and hydropower generation.

### Data

Long-term precipitation and temperature historical records (recorded monthly for 44 years) were used to investigate the temperature and precipitation trends for the period of 1970



**Figure 1** | Trarza region with the locations of the rainfall stations.

to 2013 in Trarza region in Mauritania. The data used were collected from the National Office of Meteorology of Mauritania (Office National de la Météorologie). Three rainfall stations, namely Boutilimit (station 1), Nouakchott (station 2), and Rosso (station 3), as shown in Figure 1, were used in this study. One station (Nouakchott) is outside the catchment area; however, it was considered in this study since its location is very close to the study area. Table 1 summarizes the latitude, longitude, and altitude for each station.

The maximum annual rainfall reaches 311 mm in 2003 and 226 mm in 1995 in stations 1 and 2, respectively, while station 3, which is located in the Senegal River Valley region where the rainfall is higher than other regions, behaves differently with maximum rainfall of 477.8 mm in 2010. Table 2 summarize rainfall characteristics for each station.

Annual minimum temperature (T-min), maximum temperature (T-max), and average temperature (T-average) for 1970–2013 were used in this study. These data are summarized in Table 3. Station 3 showed the maximum temperature recorded with 39.21 °C in 1987 when it was the warmest year detected at stations 1 and 2 with average of 30.28 °C and 30.48 °C, respectively. The minimum temperature in

**Table 1** | Locations of the stations

Station	Latitude (° north)	Longitude (° west)	Altitude (m)
Boutilimit (station 1)	17.54	14.69	48.59
Nouakchott (station 2)	18.07	15.95	4.44
Rosso (station 3)	16.51	15.8	6.26

**Table 2** | Annual rainfall characteristics of the stations

Station	Boutilimit (station 1)	Nouakchott (station 2)	Rosso (station 3)
Mean (mm)	146.2	89.5	238.4
Std error of mean (mm)	11.7	9.5	14.6
Median (mm)	133.8	73.5	234.8
Mode (mm)	307.2	75.9	265.5
Std deviation (mm)	77.6	62.7	97.0
Variance	6,016.2	3,930.4	9,409.4
Skewness	0.575	0.628	0.238
Std error of skewness	0.357	0.357	0.357
Kurtosis	-0.272	-0.796	-0.250
Std error of kurtosis	0.702	0.702	0.702
Range (mm)	286.1	223.2	436.7
Minimum (mm)	25.3	2.7	41.1
Maximum (mm)	311.4	225.9	477.8
Total rainfall in 44 years (mm)	6,433.8	3,936.3	10,489.0

this region was detected in 1971 at station 2 with 18.46 °C. Overall, 1974 was the coldest year in the region with the average temperature showing minimum values at stations 1, 2, and 3 of 27.46 °C, 25.06 °C, and 27.07 °C, respectively.

## METHODS

Trend analysis is considered as one of the most important issues in global climate change problems. The main purpose of the trend analysis in this study is to provide a view of change in meteorological (precipitation and temperature) variables. For this purpose, 44 years of meteorological records were used to investigate trends in the precipitation and temperature time series. The MK, SR, and Şen trend tests were used for trend identification

in the time series. The Pettitt test was used to detect the change point in the time series (Pettitt 1979) and the Thiel-Sen approach was used to estimate the magnitude of the slope in the precipitation and temperature time series.

### Mann-Kendall test

The MK test is used for the trend identification for a given time series of data. The main purpose of the MK test is to statistically investigate if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) in time. In this test, the null hypothesis  $H_0$  and the alternative hypothesis  $H_a$ , respectively, refer to non-existence and existence of trend. The MK test is calculated according to Shadmani *et al.* (2012):

$$\text{sgn}(x_i - x_j) = \begin{cases} +1 & \text{if } x_j > x_i \\ 0 & \text{if } x_j = x_i \\ -1 & \text{if } x_j < x_i \end{cases} \quad (1)$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_i - x_j) \quad (2)$$

where  $x_i$  and  $x_j$  respectively indicate the data values at times  $i$  and  $j$ , and  $n$  is the length of the data set. If  $S$  is positive, then the variable consistently increases in time; a negative value of  $S$  indicates a decreasing trend. Equation (3) is used in cases where  $n$  is larger than 10.

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^p t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

where  $p$  indicates the number of tied groups,  $t_i$  is the number of data points in the  $p$ th group. When the variance of time is

**Table 3** | Characteristics of annual temperature (maximum minimum, average) data for the stations

Station	T-min (°C)			T-max (°C)			T-average (°C)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Boutilimit (station 1)	20.4 (1975)	23.8 (2010)	22.3	34.3 (1974)	36.95 (1987)	35.69	27.46 (1974)	30.28 (2013)	29.04
Nouakchott (station 2)	18.46 (1971)	21.49 (2008)	22.22	31.4 (1974)	34.55 (1997)	33.01	25.06 (1974)	27.83 (1997)	26.61
Rosso (station 3)	19.34 (1974)	22.88 (2010)	20.6	34.65 (1976)	39.21 (1987)	36.36	27.07 (1974)	30.48 (1987)	28.71

provided in Equation (3), the standard  $Z$  can be expressed by Equation (4) as follows:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

The calculated  $Z$  value is compared with the standard normal distribution table with two-tailed confidence levels. When  $|Z| > Z_{1-\alpha/2}$  then  $H_0$  is rejected and  $H_a$  is accepted which means there is a significant trend. Otherwise,  $H_0$  is accepted and  $H_a$  is rejected which means the trend is not statistically significant. The 5% significant level which refers to  $Z_{1-\alpha/2} = 1.96$  (from the standard normal table) was used for the MK test in this study.

### Spearman's rho test

Like the MK test, the rank-based nonparametric statistical SR test is commonly used to assess the significance of monotonic trends in hydro-meteorological data time series. This method detects the existence and non-existence of trends in data time series. It can also identify if there is increase or decrease in the trend. In this test; the null hypothesis  $H_0$  means that the given data are independent and identically distributed in time, while the alternative hypothesis  $H_a$  indicates that a trend exists. The SR test statistic  $D$  and the standardized test statistic  $Z_{SR}$  are calculated by Equations (5) and (6), as follows (Shadmani *et al.* 2012).

$$D = 1 - \frac{6 \sum_{i=1}^n (R(X_i) - i)^2}{n(n^2 - 1)} \quad (5)$$

$$Z_{SR} = D \sqrt{\frac{n-2}{1-D^2}} \quad (6)$$

where  $R(X_i)$  is the rank of  $i$ th observation  $X_i$  in the sample size ( $n$ ). In this test,  $H_0$  is rejected and  $H_a$  is accepted if  $|Z_{SR}| > 2.08$  for the 5% significance level. Positive values of  $Z_{SR}$  indicate trend increase, while the negative values indicate trend decrease.

### Sen trend detection test

This method is based on dividing the time series of the data in to two equal parts, ranking them from the highest to the lowest and then plotting data points against each other in which the first sub-series ( $X_i$ ) is located on the  $x$ -axis, and the other sub-series ( $X_j$ ) is located on the  $y$ -axis on the Cartesian coordinate system. If the data points are clustered on the 1:1 (45°) straight line there is no trend; if the data points are in the triangular area below the 1:1 straight line there is a decreasing trend in the time series; and if the data points are in triangular area above the 1:1 straight line, there is increasing trend in the time series. The high, medium, and low values of the given data can be graphically evaluated in this approach (Sen 2012).

### Theil-Sen approach

This method is used to calculate the magnitude of the slope after the trend identification tests. The Theil-Sen approach can be expressed by Equation (7) (Shadmani *et al.* 2012):

$$\beta = \text{median} \left( \frac{X_j - X_i}{j - i} \right) \quad \text{for all } i < j \quad (7)$$

where  $X_i$  and  $X_j$  indicate the sequential data values of the time series in the years  $i$  and  $j$ , respectively. The calculated  $\beta$  is the estimated magnitude of the trend slope in the time series of the data.

### Pettitt's test

Pettitt's approach is commonly used to detect a single change-point of hydro-meteorological series with contentious data. For a given time series  $\{X_1, X_2, \dots, X_n\}$  with a length  $n$ , let  $t$  be the time of the change point. The samples,  $\{X_1, X_2, \dots, X_t\}$  and  $\{X_{t+1}, X_{t+2}, \dots, X_n\}$ , can be derived by dividing the time series at time  $t$ . The test statistic  $U_t$  can be expressed as (Chen *et al.* 2009):

$$U_t = \sum_{i=1}^t \sum_{j=i+1}^n \text{sgn}(x_i - x_j) \quad (8)$$

$$\text{sgn}(x) = \begin{cases} +1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} \quad (9)$$

The maximum  $|U_t|$  at time  $t$  can be considered to be the most significant change point. The approximated significance change probability  $P(t)$  for the change point can be expressed by Equation (10) as follows (Chen *et al.* 2009):

$$P(t) = 1 - \exp\left(\frac{-6U_t^2}{n^3 + n^2}\right) \tag{10}$$

When the approximated probability exceeds  $(1-\alpha)$ , the change point considered to be statistically significant level of  $\alpha$ .

## APPLICATIONS AND RESULTS

### Temperature trends

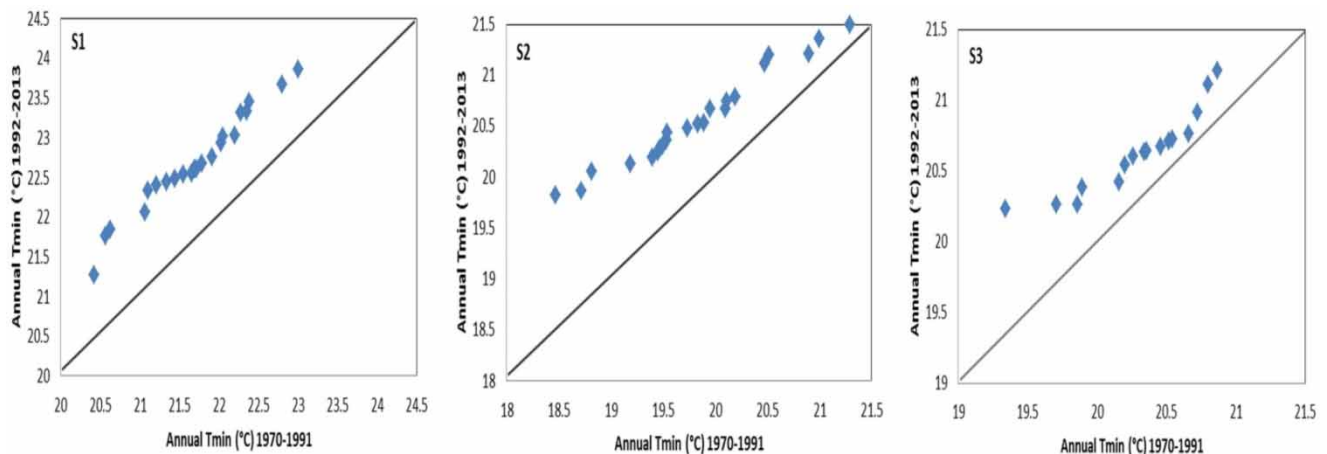
Maximum, minimum, and average annual temperature trends were investigated using different trend tests: the

MK, SR, Şen, and Pettitt’s tests. The MK, SR, and Şen tests were used for identifying trends while Pettitt’s test was used for detecting the change point in the temperature time series. Almost all the test results show an increasing trend for the three stations (see Table 4 and Figures 2–4).

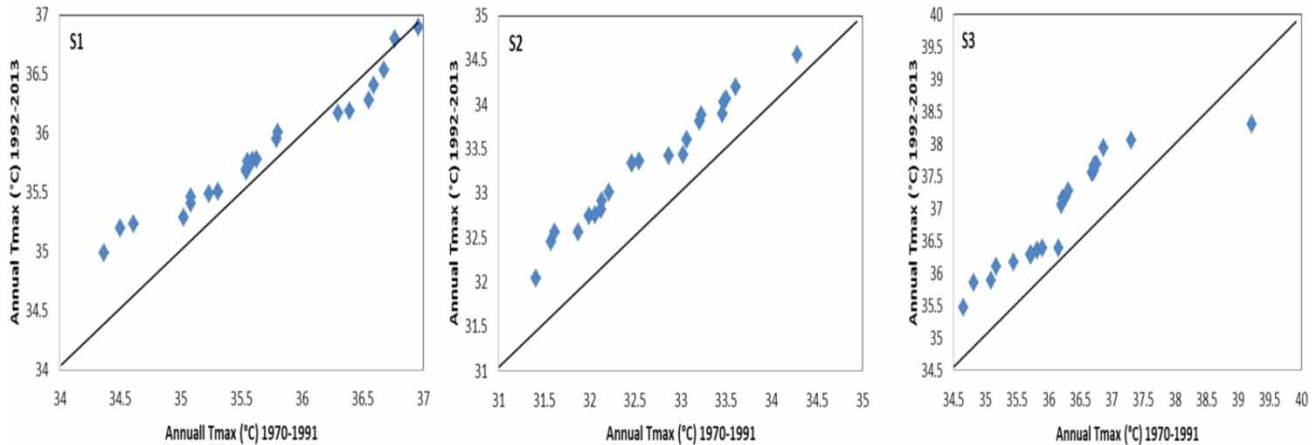
The MK and the SR tests show the same results for the three stations where they revealed significant trends in the minimum and average temperature in all the stations. The significant maximum temperature trends were observed at Nouakchott and Rosso stations, while no trend was observed in the maximum temperature records at Boutilimit, as shown in Table 4. After the trends had been identified by the MK and SR tests, the Theil–Sen approach was applied to estimate the magnitude of the slope (change per unit time). It showed that the annual average temperature increased at Boutilimit, Noakchott, and Rosso at a rate of 0.2, 0.3, and

**Table 4** | Temperature analysis results detected by the MK, SR, Theil–Sen, and Pettitt’s tests

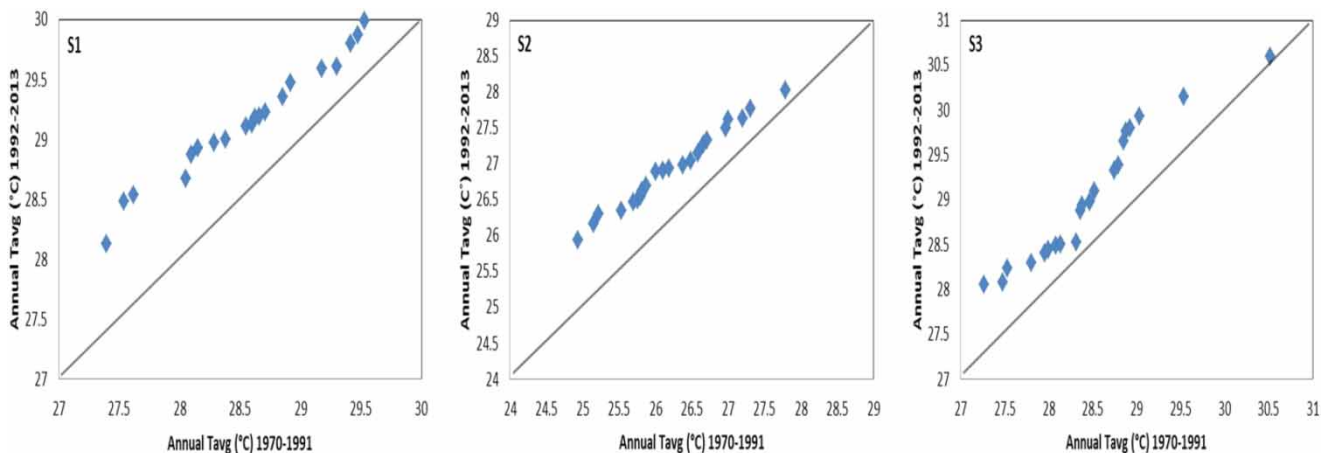
Station	Annual temperature (°C)	MK (Z)	SR (Z <sub>SR</sub> )	Trend	β (rate of increase per decade (°C))	Pettitt’s test (change point)	β (rate per decade (°C)) in 1970–1995	B (rate per decade (°C)) in 1995–2013
Boutilimit (station 1)	T <sub>max</sub>	0.43	0.744	No	–	–	–	–
	T <sub>min</sub>	4.70	7.26	Yes (+)	0.4	1995	0.33	0.43
	T <sub>avg</sub>	2.92	3.72	Yes (+)	0.2	1995	0.01	0.3
Nouakchott (station 2)	T <sub>max</sub>	2.45	3.12	Yes (+)	0.2	1995	0.1	0.14
	T <sub>min</sub>	4.46	5.80	Yes (+)	0.4	1995	0.53	0.05
	T <sub>avg</sub>	3.69	5.07	Yes (+)	0.3	1995	0.2	0.08
Rosso (station 3)	T <sub>max</sub>	2.63	3.02	Yes (+)	0.3	1995	0.07	0.0
	T <sub>min</sub>	3.24	4.06	Yes (+)	0.3	1995	0.17	0.98
	T <sub>avg</sub>	3.87	5.44	Yes (+)	0.3	1995	0.14	0.06



**Figure 2** | Annual minimum temperature (Tmin (°C)) of Boutilimit (S1), Nouakchott (S2), and Rosso (S3) stations by Şen trend test.



**Figure 3** | Annual maximum temperature ( $T_{max}$  °C) of Boutilimit (S1), Nouakchott (S2), and Rosso (S3) stations by Şen trend test.



**Figure 4** | Annual average temperature ( $T_{avg}$  °C) of Boutilimit (S1), Nouakchott (S2), and Rosso (S3) stations by Şen trend test.

0.3 °C per decade (Table 4). Abrupt changes in the annual temperature (maximum, minimum, and average) were detected by Pettitt's test for the results for all stations (Table 4). Significant abrupt change was detected in 1995.

The Şen trend test was used to investigate the trends especially in terms of the evaluation of low, medium, and high values of the temperature data. The results show significant increasing trends for the low values at all stations, compared to the high and average values which are closer to the 1:1 line (Figures 2–4). Maximum temperatures recorded at Boutilimit show different results: the medium values have almost no trend, the high values have decreasing trend, and low values have increasing trend.

### Precipitation trends

The three rain-gauge stations of Boutilimit, Nouakchott, and Rosso were used for analyzing the annual precipitation time series. The MK and SR tests showed the same result, both detecting significant increasing trends for Boutilimit and Rosso while no trend was seen for Nouakchott. Using the Theil–Sen method, the annual precipitation was found to increase at a rate of (+)3.35 and (+)2.93 mm per year at Boutilimit and Rosso stations, respectively (Table 5). The change points in Boutilimit and Rosso stations were found to be 1988 and 1993, respectively (Table 5).

Unlike the MK and the SR tests, the Şen trend test shows significant increasing trends for all stations for the

**Table 5** | Precipitation analysis results detected by the MK, SR, Theil–Sen, and Pettitt’s tests

Station	MK (Z)	SR (Z <sub>SR</sub> )	Trend	$\beta$ (rate of increase per year in mm)	Pettitt’s test (change point time)
Boutilimit (station 1)	3.12	3.43	Yes (+)	2.93	1988
Nouakchott (station 2)	1.62	1.84	No	–	–
Rosso (station 3)	2.86	3.42	Yes (+)	3.35	1993

annual precipitation time series, with the same trend magnitude (slope) (Figure 5).

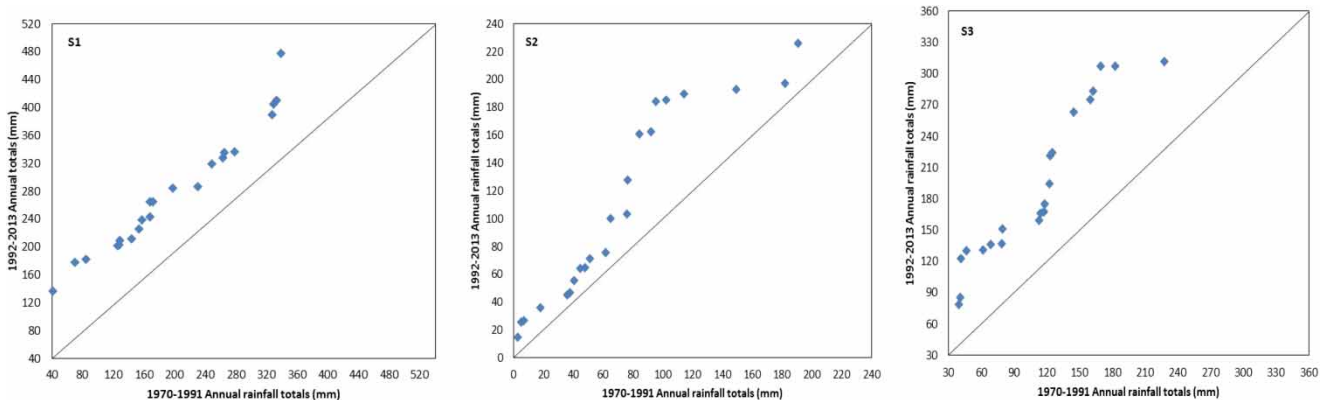
### DISCUSSION

Trends in temperature and precipitation for the period 1970–2013 were analyzed for Trarza region using different types of trend detection methods. The results showed that there were positive trends in precipitation and temperature during the period studied. Although all stations have slight increasing precipitation and temperature trends, they differ in terms of trend direction changes (slope and jumps).

The annual regional temperature time series analysis indicates that the changes in temperature over 1970–2013 reflect warming of the region as a whole. The annual average temperature increased at a rate of 0.2, 0.3, and 0.3 °C per decade at Boutilimit, Nouakchott, and Rosso stations, respectively. This increase of average temperature is

affected by the minimum more than the maximum temperatures as seen in Table 4. The maximum values increased at the rate of 0.2 and 0.3 °C per decade for stations of Nouakchott and Rosso, respectively, and no trend in the maximum temperature was detected in station of Boutilimit. While the minimum temperatures have significant positive trends detected at all stations, the magnitudes of the increasing trend for the minimum temperatures for stations Boutilimit, Nouakchott, and Rosso were found to be 0.2, 0.4, and 0.3 °C per decade, respectively. The Sen trend test showed that the low values of temperatures (maximum, minimum, and average) increased more than the medium and high values during the study period of the (1970–2013). The abrupt change in the annual temperatures (maximum, minimum, and average) was detected in 1995 for all stations and this means that the region had significant jump in the trend direction in that year. The magnitudes in two periods: 1970–1995 and 1995–2013 were calculated and the results showed the rise of the average temperature in the first period (1970–1995) for Nouakchott and Rosso; in contrast at Boutilimit the increase of the temperature was detected in the second period (1995–2013) (see Table 5).

Analyzing annual precipitation time series by MK and SR tests showed that two stations (Boutilimit and Rosso) have significant positive trends while no trend was detected for Nouakchott station. However, the Sen test showed different results by detecting a positive trend for station Nouakchott, but in terms of the medium values of precipitation during 1970–2013. The results of the Theil–Sen test



**Figure 5** | Annual rainfall of Boutilimit (S1), Nouakchott (S2), and Rosso (S3) stations by Sen trend test.



showed that the most significant positive trend was detected at Rosso station with value of 3.35 mm per year while the precipitation for Boutilimit station increased at 2.93 mm per year. Abrupt changes in annual precipitation were detected in 1988 for Boutilimit and in 1993 for Rosso.

## CONCLUSIONS

Based on historical precipitation and temperature data recorded for 1970–2013 from three stations in Trarza region in Mauritania, this study investigated the performances of five trend tests for the precipitation and temperature time series. The following conclusions were drawn:

1. The annual average temperature time series analysis indicates that the changes in temperature over 1970–2013 reflect warming for the region as a whole.
2. The annual temperature is increasing about 0.3 °C per decade.
3. Significant increasing trends for the low values of temperature in all the stations are occurring, compared to the high and the medium values.
4. The abrupt change in temperature was detected in 1995 for the whole region.
5. The precipitation time series has positive trend detected for two stations (at the rate of 3.35 mm per year in Boutilimit and 2.93 mm per year in Rosso) while no trend is detected in the other (Nouakchott).
6. Significant increasing trend is revealed for all the values (high, medium, and low), with almost the same trend magnitude (slope).

As a result of hotter climate and erratic rainfall, much of Mauritania has become progressively more unsuitable for agriculture and villages. Irregular rain has ruined crops, and the country is experiencing both droughts and floods making arable land unsuitable for cultivation. More than 5,600 people countrywide have been affected by the floods, with over 2,000 people having to evacuate their homes in 2013, according to the International Federation of Red Cross and Red Crescent Societies (IFRC). However, Mauritania has been experiencing drought since the late 1960s; Trarza region experienced almost 8 drought years during 1970–2013 (Yacoub & Tayfur 2016). Therefore, the

government should work on suitable adaptation strategies for agricultural system with the existing climate conditions. This study would be a guide and help in that direction.

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